

CAAP Quarterly Report

Date of Report: *December 31, 2019*

Contract Number: 693JK31950005CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *An Unmanned Aerial System of Visible Light, Infrared and Hyperspectral Cameras with Novel Signal Processing and Data Analytics*

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For quarterly period ending: *December 31, 2019*

Business and Activity Section

(a) Generated Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Dr. Bo Shang, a post doc at Missouri S&T, will join the research team on January 18, 2020. Dr. Shang is responsible for the hardware and software integration of visible light, infrared and hyperspectral cameras and associated validation tests under Dr. Chen's supervision. Mr. Pengfei Ma, a Ph.D. student in civil engineering at Missouri S&T, was on board since November 15, 2019. Mr. Ma is responsible for the laboratory and field tests of an integrated system of visible light, infrared and hyperspectral cameras and for image analysis under Drs. Chen and Shang's supervision. Mr. Jiao Pu, another Ph.D. student in civil engineering at Missouri S&T, was on board since October 1, 2019. Mr. Pu is responsible for the finite element model of an unmanned aerial system with cameras.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

This project aims to:

1. Develop and integrate a robust and stable, semi- or fully-automated UAS with multiple sensors for multi-purpose pipeline safety data collection,
2. Explore and develop novel signal and image processing techniques for data analytics, damage assessment, and condition classification, and
3. Evaluate and validate field performance of the integrated UAS for pipeline safety inspection.

These objectives will be achieved through analytical, numerical, and experimental investigations in three tasks:

- 1 To design and prototype the UAS for the collection of cohesive types of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers;
- 2 To develop and validate one-dimensional (1D) spectral analysis at each pixel of a hyperspectral image, two-dimensional (2D) image classification of changes, spatial analysis of a hyperspectral

image and its fusion with other images for increased probability of detection, and three-dimensional (3D) object establishment for volume estimates; and

- 3 To develop a physically-interpretable, deep learning neural network for the selection of images (frames) with regions of interest from long hours of video footage, recorded as the unmanned vehicle flies along a pipeline, and demonstrate in field conditions the UAS performance in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground objects, accident responses, and mapping system accuracy.

The project tasks will be executed over a period of 12 quarters (3 years) with eight milestones as defined below.

Task	2019	2020				2021				2022		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1	√	√	√	√	√	√						
2	√	√	√	√	√	√	√	√	√	√	√	√
3					√	√	√	√	√	√	√	√

Tasks 1-3 have two (M1-M2), four (M3-M6), and two (M7-M8) milestones, respectively. These milestones are described as follows:

- M1. Integration of infrared and hyperspectral cameras into a hexacopter or octocopter,
- M2. Demonstration of hyperspectral imaging capability to identify ground changes,
- M3. Demonstration of 1D AWT spectral analysis of hyperspectral images,
- M4. Demonstration of 2D AWT spatial analysis of visible light and thermal images,
- M5. Demonstration of a new feature of hyperspectral image and fusion of images,
- M6. Demonstration of 3D object establishment for spill size and trajectory estimate,
- M7. Demonstration of a deep-learning neural network for selection of regions of interest, and
- M8. Field performance report of the integrated UAS.

Task 1. Design and prototype the UAS for the collection of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers.

A Duo Pro R640 camera (FLIR), as shown in Fig. 1(a), and a VBIR-SWIR hyperspectral camera (Headwall), as shown in Fig. 1(b), will be potentially integrated into an unmanned aerial system (UAS) that is installed on a custom-designed hexacopter, as illustrated in Fig. 1(c). The Duo Pro R640 camera includes a visible Len and an infrared Len arranged in parallel. The infrared Len can be used to take a thermographic image based on thermal radiation, and the visible Len is for a photographic image based on visible light reflection. The infrared camera has a measurement accuracy of $\pm 5^\circ\text{C}$ or 5% of readings between -25°C and $+135^\circ\text{C}$, and a thermal sensor resolution of 640×512 in space. The hyperspectral camera equips conventional spectroscopy with the capability of spatial/spectral information acquisition based on light reflection from a surface, greatly enhancing abnormality detection abilities and extending application scopes. The hyperspectral image has a sensor spatial and spectral resolution of 640 and 271 pixels, respectively. Unlike remote sensing via satellites, rapid improvements in camera resolution and stabilizer can further enhance video clarity and details particularly from close views obtained via a UAS.

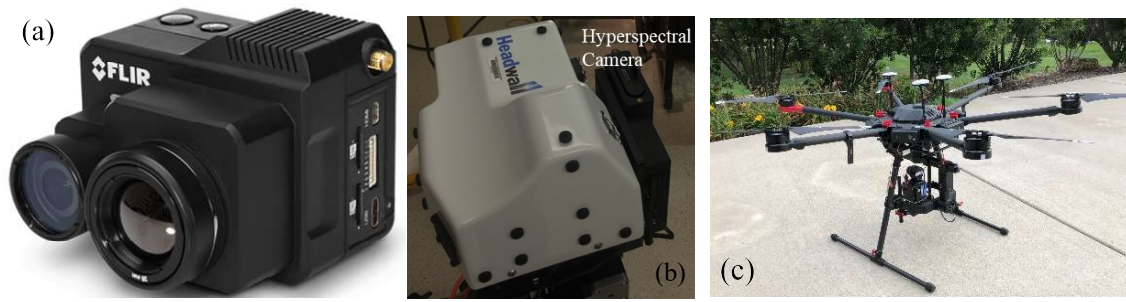


Fig. 1 Key components in the proposed UAS for pipeline inspection: (a) dual-sensor visible light and infrared camera, (b) VNIR-SWIR hyperspectral camera, and (c) hexacopter equipped with a hyperspectral camera

In this quarter, the manufacture specifications of the two cameras were further reviewed and analyzed to ensure they would be appropriate for this project application. In addition, a finite element model of the hexacopter started to be established. In particular, one of the four blades in the hexacopter was scanned using a 3D laser scanner (NextEngine 3D Scanner Ultra HD, <http://www.nextengine.com/assets/pdf/scanner-techspecs-uhd.pdf>), as presented in Fig. 2(a). Point clouds were pulled into the Solidworks software and cleansed for visualization as illustrated in Fig. 2(b). The clean model in Fig. 2(c) was compared with its prototype in Fig. 2(d).

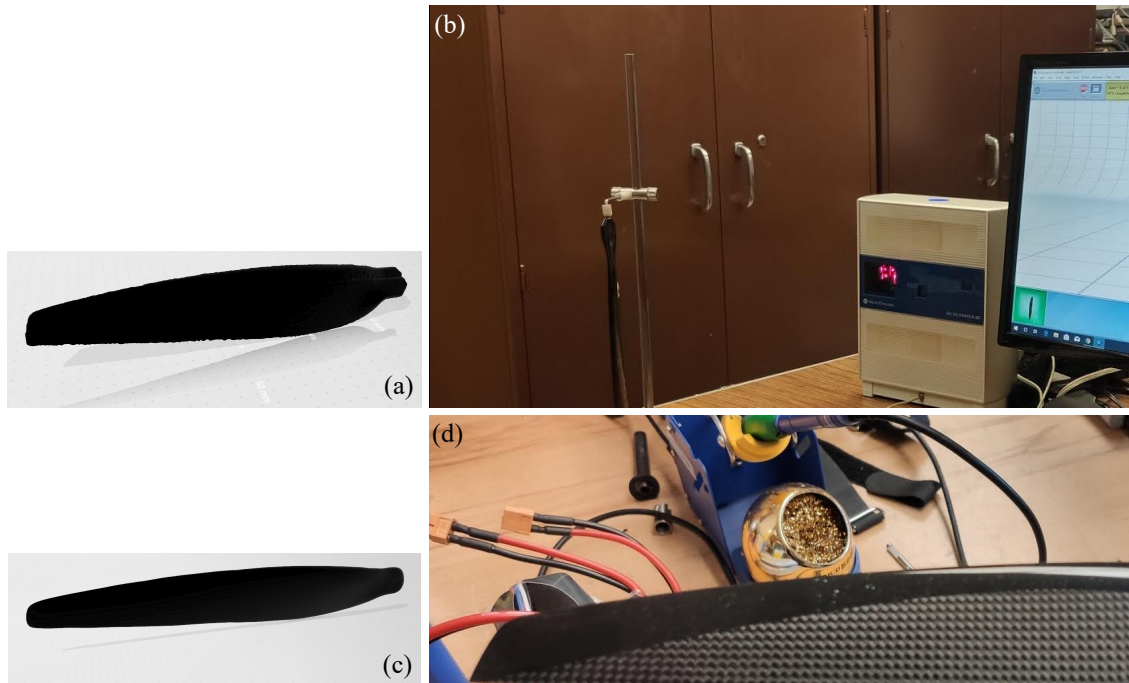


Fig. 2 Modeling of a blade of the hexacopter: (a) raw data taken from the 3D scanner, (b) 3D scanner and point clouds in SolidWorks, (c) clean model, and (d) blade prototype

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

Literature reviews were underway to understand the latest development in pipeline condition inspection and assessment with remote sensing. In particular, one-dimensional (1D) spectral analysis at each pixel of a hyperspectral image began with the extended 1D adaptive wavelet transform to understand its general behavior.

Task 3. Develop a physically-interpretable neural network for the selection of images (frames) from video footage and demonstrate in field conditions the UAS in the assessment of pipeline and surrounding conditions, population-impacted changes, above-ground objects, accident responses, and mapping system accuracy.

This task will not start till the 4th quarter in 2020.

(c) Planned Activities for the Next Quarter - The following activities will be executed during the next reporting quarter.

Task 1. Design and prototype the UAS for the collection of images from visible light, infrared, and hyperspectral cameras, and demonstrate the potential of the collected images for the evaluation of ground conditions and pipeline risks for decision makers.

To continue to develop the finite element model of a conceived hexacopter under balanced camera and accessory weights to ensure it is structurally sound, and then procure parts for the fabrication of custom-made connectors to integrate infrared and hyperspectral cameras into the UAS prototype.

Task 2. Develop and validate 1D spectral analysis at each pixel of a hyperspectral image, 2D image classification of changes, spatial analysis of a hyperspectral image and its fusion with others for increased probability of detection, and 3D object establishment for volume estimates.

The 1D adaptive wavelet transform will be applied to extract the ground and material conditions along a pipeline through the abnormalities in space, which are represented by the changes in wavenumber. The effectiveness of the extended transform will be investigated using the data obtained in Task 1 from laboratory tests, once available.